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14. ABSTRACT
The development of high-order methods (order of accuracy > 2nd order) on unstructured grids is widely viewed as a major pacing item in computational fluid dynamics (CFD). Efficient high-order methods capable of handling complex geometries are required to compute vortex dominated flows, and to perform large eddy simulation and direct numerical simulation with complex configurations, and to predict aeroacoustic noise generation and propagation. The primary objective of the present research is to develop implicit, multigrid and adaptive solution algorithms for a promising high-order method, the spectral difference (SD) method.
Several major activities were carried out:
• The development of a hp-adaptation capability to capture both discontinuous and smooth flow features with high efficiency;
• Development of a accuracy-preserving limiter for discontinuity-capturing for the high-order SD Navier-Stokes solver;
• Demonstration of the developed code for real world unsteady vortex-dominated flow problems;

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IMPLICIT AND P-MULTI-GRID ALGORITHMS FOR HIGH-ORDER SPECTRAL DIFFERENCE METHOD ON UNSTRUCTURED GRIDS

AFOSR GRANT FA9550-06-1-0146

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Abstract

The development of high-order methods (order of accuracy > 2nd order) on unstructured grids is widely viewed as a major pacing item in computational fluid dynamics (CFD). Efficient high-order methods capable of handling complex geometries are required to compute vortex dominated flows, and to perform large eddy simulation and direct numerical simulation with complex configurations, and to predict aeroacoustic noise generation and propagation. The primary objective of the present research is to develop implicit, multigrid and adaptive solution algorithms for a promising high-order method, the spectral difference (SD) method.

Several major activities were carried out:

- The development of a hp-adaptation capability to capture both discontinuous and smooth flow features with high efficiency;
- Development of a accuracy-preserving limiter for discontinuity-capturing for the high-order SD Navier-Stokes solver;
- Demonstration of the developed code for real world unsteady vortex-dominated flow problems;

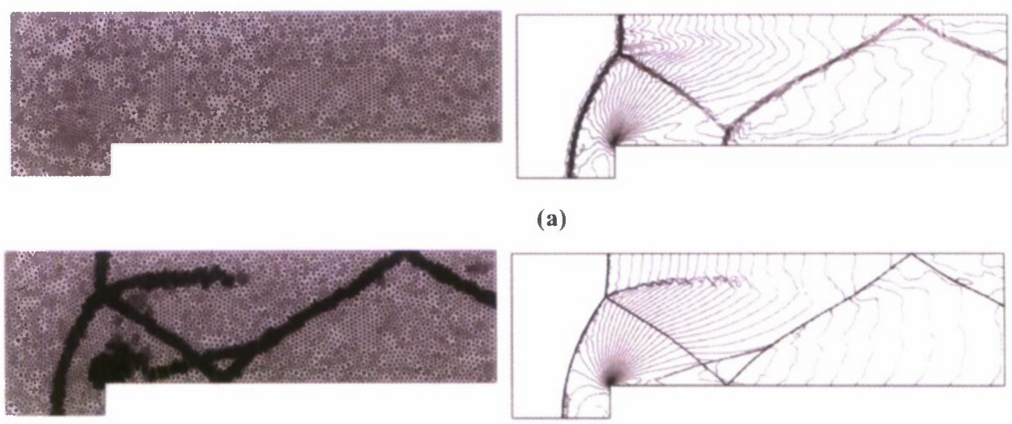
Significant Achievements

- An hp-grid adaptation capability has been developed for the 2D Euler solver, and also demonstrated for both steady and unsteady flow problems. Shown in Figure 1 are the original and adapted grids and the corresponding density contours for a Mach 3 flow inside a wind tunnel with a step. Grid adaptation was used to automatically refine regions of discontinuity and fine flow features to achieve high efficiency.

- The 3D SD solver has been successfully used to perform implicit large eddy simulation for flow over a corrugate dragonfly wing, which has nice lift performance under low Reynolds number condition. Preliminary simulation results indicate the flow solver is capable of predicting the stall at high angle of attack. Shown in Figure 2 is the instantaneous iso-surfaces of the vorticity magnitude, and the simulation agree well qualitatively in terms of flow topology. The computed lift coefficient history is shown in Figure 3, with comparison with the averaged experimental lift

coefficient. Note that there is very good agreement between the present simulation and experiment, demonstrating the great potential of the high-order solver.

- A hierarchical moment limiter is being developed for high-order methods. In the design of this limiter, we adopted a "troubled cell" approach, in which cells requiring limiting are detected first. The design criterion for the detector is high efficiency because all the cells are examined. We also assume no detectors are perfect as a lack of resolution in a smooth region can be easily mistaken to be a discontinuity. Therefore we demand that the limiter can recover high-accuracy in case a smooth region is detected. An accuracy study was performed using the limiter and it was confirmed that the limiter can achieve the formal order of accuracy for smooth problems. The limiter was successfully employed to compute the transonic flow over the NACA0012 airfoil as shown in Figure 4.



(a)

(b)

Figure 1. Density contours and grid under adaptive h-refinement at time=4.0; (a) No adaptation (base grid, 26,238 DOFs); (b) 3 levels of adaptation (190,017 DOFs at last time step); Grid is refined from base grid every 100 time steps.

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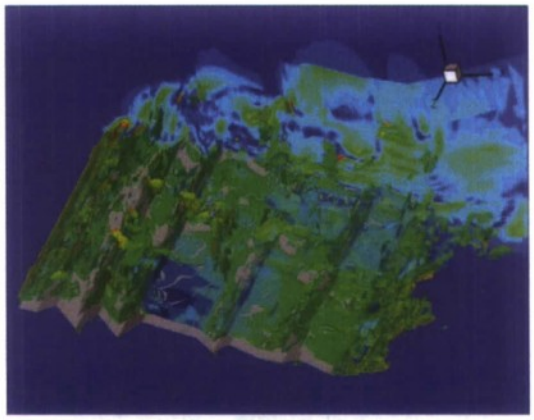

Figure 2. Transient vorticity distribution of dragonfly wing at Angle of Attack of 16 deg

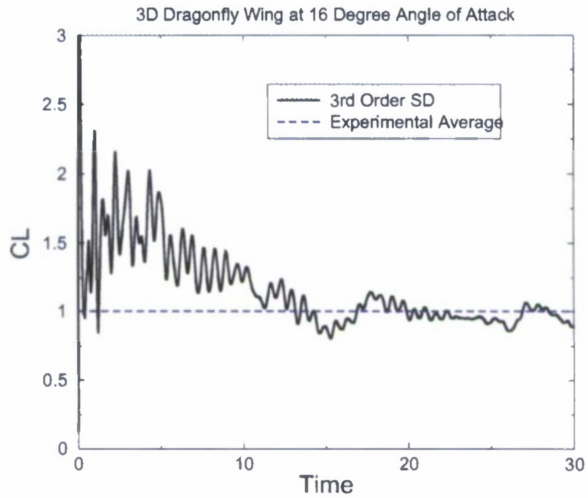

Figure 3. Computed lift history for dragonfly wing at angle of attack of 16 degree with comparison to the averaged experimental measurement

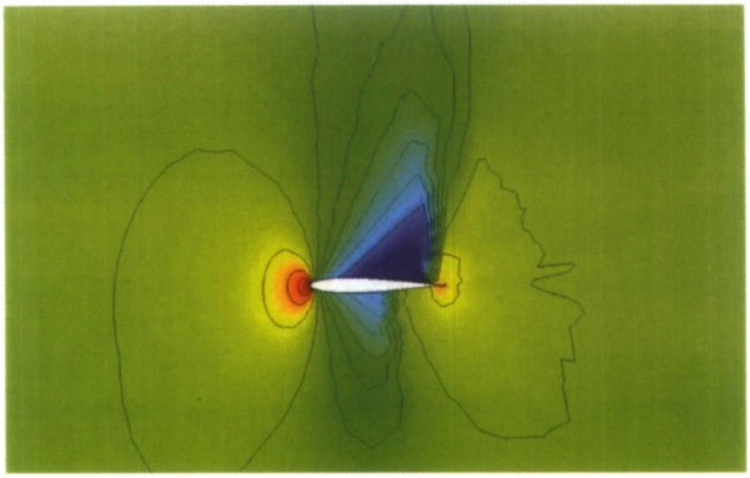

Figure 4. Density contours of transonic flow over the NACA0012 airfoil, at Mach = 0.85, α = 1 degree, computed with a hierarchical moment limiter

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Publications

- K Van den Abeele, C. Lacor and Z.J. Wang, "On the stability and accuracy of the spectral volume method," Journal of Scientific Computing, in press.
- Y. Sun, Z.J. Wang and Y. Liu,"Efficient Implicit Non-linear LU-SGS Approach for Compressible Flow Computation Using High-Order Spectral Difference Method", Communications in Computational Physics, in press.

- C. Liang, R. Kannan and Z.J. Wang, "A p-multigrid Spectral Difference method with explicit and implicit smoothers on unstructured triangular grids," Computers & Fluids, in press.
- R. Harris, Z.J. Wang and Y. Liu, "Efficient Quadrature-Free High-Order Spectral Volume Method on Unstructured Grids: Theory and 2D Implementation," Journal of Computational Physics, Volume 227, No. 3, pp. 1620-1642 (2008).
- R. Harris and Z.J. Wang, High-Order Adaptive Quadrature-Free Spectral Volume Method on Unstructured Grids, AIAA-2008-779.
- H. Gao, H. Hu and Z.J. Wang, Computational Study of Unsteady Flows around Dragonfly and Smooth Airfoils at Low Reynolds Numbers, AIAA-2008-385.
- R. Kannan, Y. Sun and Z.J. Wang, A Study of Viscous Flux Formulations for an Implicit P-Multigrid Spectral Volume Navier Stokes Solver, AIAA-2008-783.

Honors & Awards Received

- Doctor of Science in Engineering, University of Glasgow, July 2008.
- Promoted to Professor of Aerospace Engineering, May 2008.

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Transitions

The developed method was used in the DARPA "Helicopter Quieting" project. Contact person: Dr. C.L. Chen, cchen@teledyne.com, (805)373-4181. In addition, a STTR proposal with CFD Research Corporation was submitted to the Air Force Office of Scientific Research. Contact person: Dr. Paul Dionne (pjd@cfdrc.com).